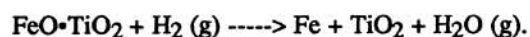


THERMODYNAMICS OF LUNAR ILMENITE REDUCTION; B.H. Altenberg, H. A. Franklin, C. H. Jones, Bechtel, San Francisco, CA

With the prospect of returning to the moon, the development of a lunar occupation would fulfill one of the goals of the Space Exploration Initiative (SEI) of the late 1980's. Processing lunar resources into useful products, such as liquid oxygen for fuel and life support, would be one of many aspects of an active lunar base. Ilmenite (FeTiO_3) is found on the lunar surface and can be used as a feedstock to produce oxygen. Understanding the various ilmenite-reduction reactions elucidates many processing options. Defining the thermodynamic chemical behavior at equilibrium under various conditions of temperature and pressures can be helpful in specifying optimal operating conditions. Differences between a previous theoretical analysis (Hernandez and Franklin, 1992) and experimentally determined results (Gibson et al., 1988) has sparked interest in trying to understand the effect of operating pressure on the hydrogen-reduction-of-ilmenite reaction. The overall reaction can be written



This equation demonstrates no change in the number of moles of gas present as reactant compared to the number of moles of gas present as product. Basic theory suggests that this reaction should be pressure independent. A computer simulation (Roine et al., 1989) was used to model the theoretical reduction of ilmenite with hydrogen as a function of temperatures (at $T = 900^\circ\text{C}$, 1000°C , 1100°C , and 1200°C) and pressures ranging from 10^{-3} bar to 10^{+4} bar. This was done to gain insight as to the effect operating pressure can have on how water is won from the reduction of ilmenite with hydrogen.

For the reduction of ilmenite with hydrogen, several important conclusions are obtained. Figure 1 describes the variations in the composition equilibrium constant, K_x , as a function of pressure. At very low pressures (10^{-3} bar to 0.2 bar), K_x increases with increasing pressure. At higher pressures (20 bar to 10^{+4} bar) K_x also increases with increasing pressure. In both of these regions the ratio of water vapor product to hydrogen reductant increases. Between these two pressure regimes, there exists a transition pressure range (0.2 bar to 20 bar). The trends seen in the lowest and highest pressures regions agree with those seen in the experimental work by Massieon (1992) and by Gibson et al. (1988). The points in the transition region correspond to those reported by Hernandez (1992). The computer model, HSC, uses an extensive base of empirical thermochemical data in computing the standard Gibbs function of the reaction. However, the authors of this abstract are now comparing the results to work by MacChesney and Muan (1961), Merritt and Turnbull (1974), Grey and Merritt (1981), and Borowiec and Rosenquist (1981), which deal with the stability of various solid species present in the Fe-Ti-O system. In addition, the results presented in Figure 1 are based on a model of a closed system. The simulation data presented in Figure 1 still needs to be tested in the laboratory before accepting it as a reflection of the real system. In particular, extrapolation to very high and very low pressures will need confirmation.

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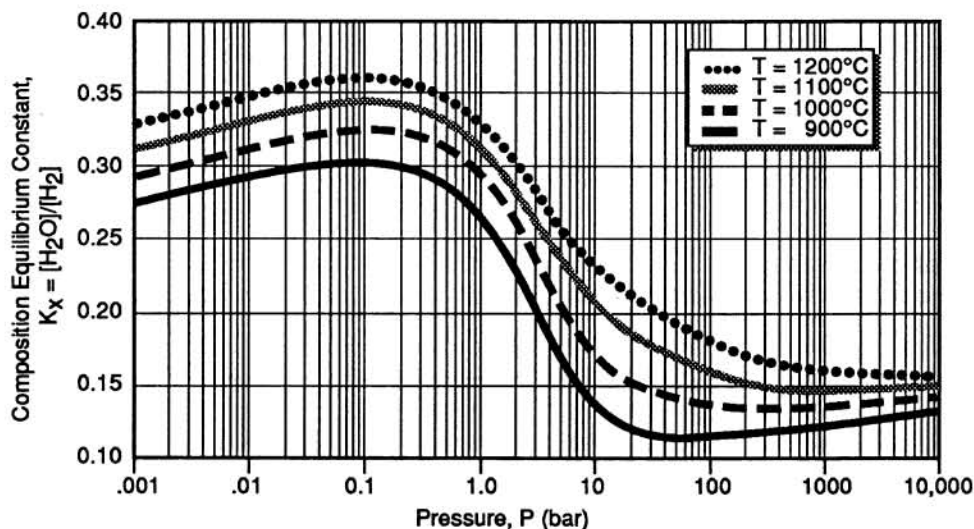


Figure 1 Composition Equilibrium Constant as a Function of Temperature and Pressure

The modeling performed in the generation of Figure 1 has provided insight into the effect of pressure on the reduction of ilmenite with hydrogen to form water and various solid species. It will be important to determine more precisely how the amounts of gas species and different solid species at equilibrium depend on the temperature and pressure of the system. The results to date indicate that, in the lower pressure range, the water vapor is obtained almost exclusively from the reduction of iron oxide to iron. In the highest pressure range, the water vapor obtains some of its oxygen from partially reduced oxides of titanium. The presence of these solid species was also noted in work by Allen et al. (1992).

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